Theory of Spin-Wave Emission from a Rectangular Anisotropy Defect

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Abstract. An analytical theory of spin wave emission due to a one-dimensional non-uniformity of magnetic anisotropy ("defect") is presented. When excited by a continuous, harmonic external magnetic field oriented orthogonal to the easy magnetisation axis, plane spin waves are emitted above a threshold frequency. We find conditions for excitation of standing spin waves inside the defect, and thus conditions of zero emission, which depend on the defect width and wavelength of spin waves within the defect.

Introduction

Exchange spin-waves (SWs) have great potential as information carriers on the nanoscale, due to their short wavelengths and **isotropic, quadratic** dispersion [1-2].

The wavelengths of SWs generated via **electrical antennas** or point contacts are **limited** by the **size** of the device [2].

An alternative method of SW generation could be via **anisotropy defects**, etched or embedded into the sample [3].

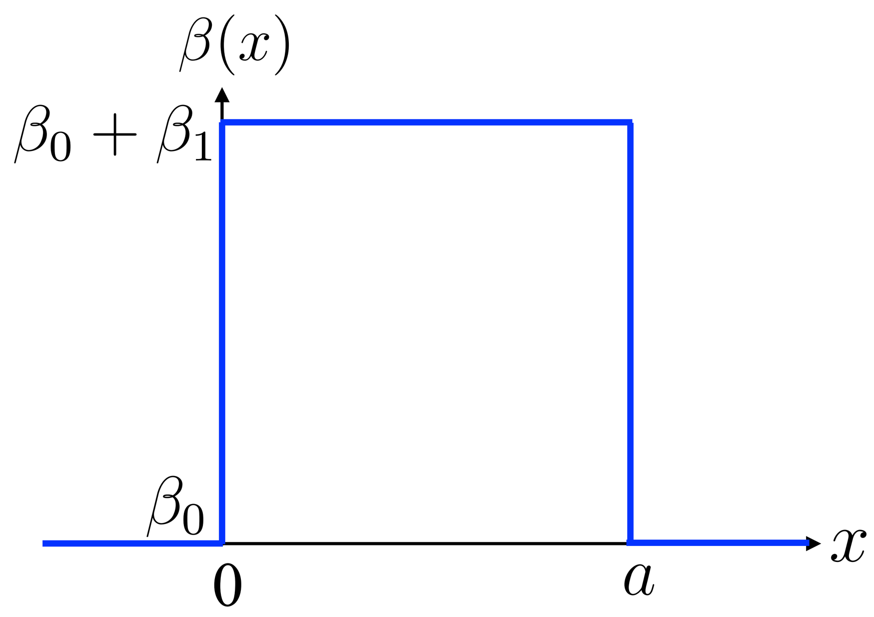

Fig.1: Magnetic anisotropy $\beta(x)$ in form of a rectangular profile.

We use analytical theory to describe this phenomena for **exchange SWs**.

We model an infinite sample, with a one-dimensional **anisotropy defect**, adapting the work in [3] to the case of a **rectangular profile** (Fig.1).

Background Theory

The ferromagnet is in a uniform magnetic field $\mathbf{H}_0$, uniaxially magnetised along the z direction.

Excitation of the sample via an in-plane, time-varying magnetic field $\mathbf{h}(t)$ induces **precession** of the magnetisation $\mathbf{M}$ (Fig.2), described by the **Landau-Lifshitz equation** without damping:

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma[\mathbf{M}\times\mathbf{H}_{eff}]$$

gyromagnetic ratio

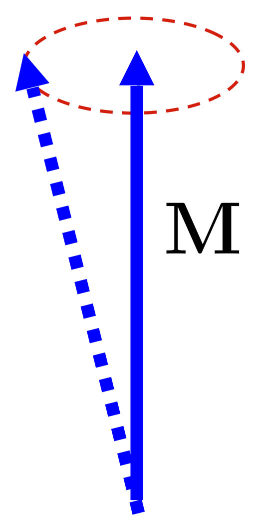

Fig.2: The linear approximation assumes that $\mathbf{M}$ undergoes a small amplitude precession.

The effective field $\mathbf{H}_{eff}$ is the functional derivative of the free energy density W:

$$W = \underbrace{\frac{1}{2}\alpha\left(\frac{\partial \mathbf{M}}{\partial x_i}\right)^2}_{\text{Exchange}} - \underbrace{\frac{\beta(x)}{2}(\mathbf{M}\cdot\mathbf{n})^2}_{\text{Anisotropy}} - \underbrace{\mathbf{M}\cdot\mathbf{H}_0}_{\text{Zeeman}} - \underbrace{\mathbf{M}\cdot\mathbf{h}(t)}_{\text{Excitation}}.$$

We **linearise** the Landau Lifshitz equation and solve for $\tilde{\mathcal{M}}_\beta$, which describes the excitation of the magnetisation due to the defect:

$$\alpha\nabla^2\tilde{\mathcal{M}}_\beta + [\mp\Omega(\omega) - \beta_0 - \beta_1(x)]\tilde{\mathcal{M}}_\beta = \beta_1(x)\frac{\tilde{h}(\omega)}{\mp\Omega(\omega)-\beta_0}$$

exchange constant *effective frequency* *Fourier transform of* $\mathbf{h}(t)$

Results & Discussion

- **Plane SWs emitted** for frequency: $\Omega > \beta_0$ (Fig.3).
- $ak_1 = 2n\pi$ ⇒ **standing wave** in defect (Fig.4).

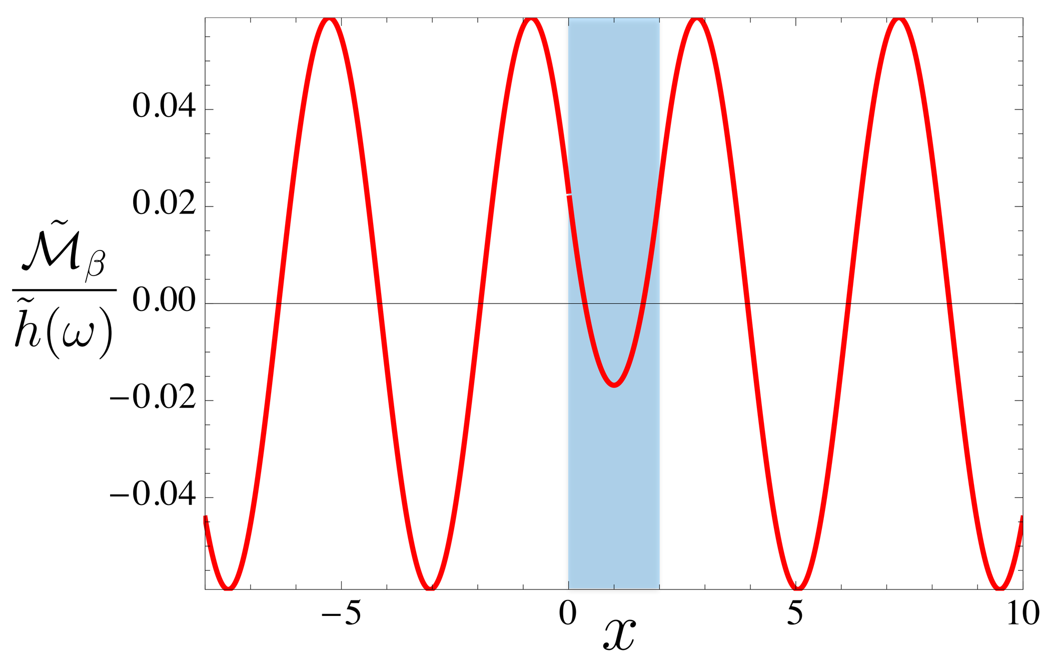

Fig.3: SWs emitted from the defect (indicated by shaded region), for $\alpha = \beta_0 = 1$, $\Omega = 3$ & $\beta_1 = 1.5$.

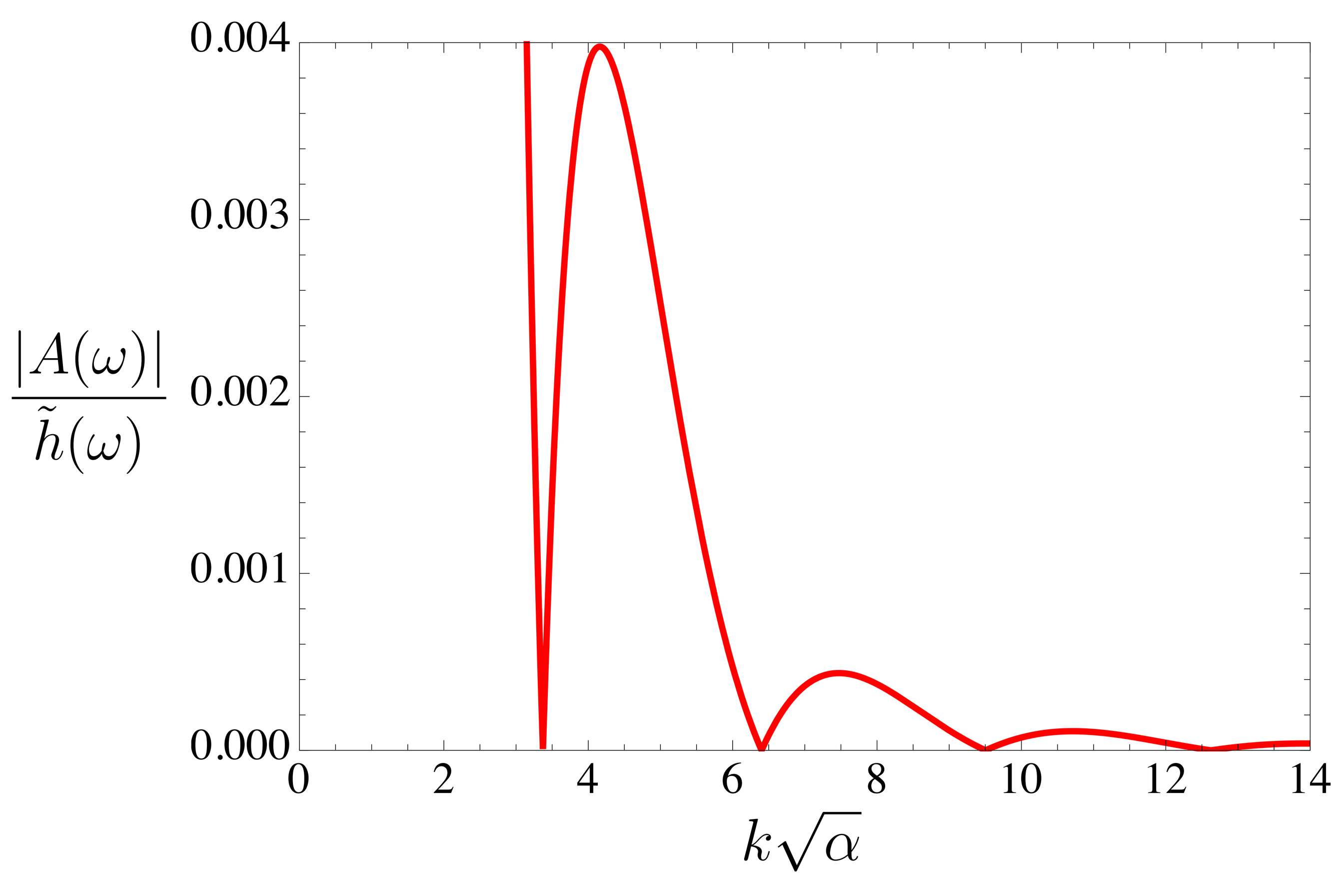

Fig.4: Amplitude of $\tilde{\mathcal{M}}_\beta$ outside of the defect, $|A(\omega)|$, vs. wave vector outside of the defect, k_0 (both normalised).

No SWs emitted if the wave vector inside the defect, k_1, satisfies:

$$ak_1 = 2n\pi$$

Future Work

- Extending the theory to magnetostatic spin waves.
- Developing a detailed theoretical understanding of how a graded magnonic index profile can lead to the emission of spin waves.

References

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